Stellar properties, reference stars, habitable zone

Known exoplanets around nearby stars (Mai 2012)

Known planets:
- Stars without known planets
- Stars with habitable planets (Gliese 581)
- Stars with planets

No known planets:
- 6%
- 0.1%
- 94%

Expectations (wait update with Kepler data)
- Stars without known planets
- Stars with habitable planets (Gliese 581)
- Stars with planets
- Stars with earth-like planets

Known exoplanets around nearby stars (Mai 2012)

Crossmatch between Hipparcos and the exoplanet encyclopedia

L ~ M^3.5

Columns:
- All Hipparcos columns
- and derived NEAT columns

Rows:
- selected Hipparcos rows: AFGKM main sequence stars closer than 20 pc

NEAT catalog
The NEAT catalog of target stars

- Construction of the NEAT catalog from Hipparcos:
  - Loading of the Hipparcos catalog as a VOTable in Topcat
  - Selection of stars closer than 20 pc
  - Selection of the main sequence FGK stars
  - Crossmatch with the exoplanet encyclopaedia
The NEAT catalog: usages

• Crossmatch with the exoplanet encyclopaedia -> statistics about already known exoplanets

• Information about the distribution (spectral type, distance, magnitude...) of the target stars

• Crossmatch with the Tycho catalog -> statistics about reference stars

• Determination of “the NEAT columns”: habitable zone, astrometric signal in habitable zone, neat observation time

• Study of the science case, observational strategy
Properties of the NEAT targets: already known exoplanets

- 729 known exoplanets in the exoplanet encyclopaedia
- 99 are located at less than 20 pc

<table>
<thead>
<tr>
<th>Hipparcos subset</th>
<th>Exoplanets count</th>
<th>Stars count</th>
</tr>
</thead>
<tbody>
<tr>
<td>All stars &lt; 20 pc</td>
<td>92/99</td>
<td>58/934</td>
</tr>
<tr>
<td>Main sequence FGK stars &lt; 20 pc</td>
<td>61/99</td>
<td>35/340</td>
</tr>
</tbody>
</table>

Known exoplanets around nearby stars (Mai 2012)
Properties of the NEAT targets: distance

Volume limited sample for K, G and K stars

Magnitude limited sample for K, G and K stars

Coupling between radial velocities and astrometry: very close (< 10 pc) 16 M and 27 K stars with mag < 9.
Properties of the NEAT targets: Complementarity with Gaia

- NEAT look at stars with Vmag between 0 and 10
- Gaia has a bright limit of Vmag = 6
Determination of the habitable zone

\[ \frac{L}{L_{\text{sun}}} = 10^{\left(\frac{M_{\text{sun}} - M_B}{2.5}\right)} \]

MB = BC + Mv − 5 \log(D/10\,\text{pc})

Seff = f(B-V). f is piecewise linear

Seff = f(B-V)

L \sim M^{3.5}

Crossmatch between hipparcos And the exoplanet encyclopedia

St_Mass (exoplanet encyclopedia)

Table: SpType, log(Teff), B-V, Seff

Seff <--> SpType

Ref: Flower

Ref: Kastings

Ref: Kastings

Ref: Flower (log(Teff))

Ref: Kastings

L / L_{\text{sun}}

HZ inner edge

HZ outer edge

M_{\text{star}}

B-V

BC

MB

L / L_{\text{sun}} = 10^{(\frac{M_{\text{sun}} - M_B}{2.5})}

d = 1\,\text{AU} \sqrt{\frac{L}{L_{\text{sun}} \, \text{Seff}}}
Astrometric signal in the habitable zone

Astrometric signal of Earth mass planets around nearby stars

The astrometric signal is calculated for a planet of 1 Earth mass. The bars represent the inner edge and outer edges of the habitable zone, the central dot is for a distance where the bolometric luminosity is equal to that of the Earth. For more massive planets the astrometric signal is increased, as indicated by the arrow on the lower right.

NEAT: 50x3h of observation

0.28 µas

HZ outer edge

HZ inner edge

Earth-like position
Determination of the astrometric signal per hour, for each target

- Astrometric signal: 
  \[ A = 3\mu as \frac{M_{\text{planet}}}{M_{\text{Earth}}} \times \left( \frac{M_{\text{star}}}{M_{\text{Sun}}} \right)^{-1} \times \frac{R(\text{AU})}{1\text{AU}} \times \left( \frac{D(\text{pc})}{1\text{pc}} \right)^{-1} \]

\[ \sigma = A/\text{SNR} \Rightarrow \frac{\sigma_0}{\sqrt{T_{\text{visit}}N_{\text{indep.data}}}} = A/\text{SNR} \Rightarrow T_{\text{visit}} = \frac{\text{SNR}^2 \sigma_0^2}{A^2 N_{\text{indep.data}}} \]

\[ \sigma_{\text{ref}}^2 = \sigma_{\text{ref.0}}^2 \times \frac{F_{\text{base}}}{F_{\text{ref}}} \]

\[ \sigma_0 = \sqrt{\sigma_{\text{ref}}^2 + \sigma_{\text{target}}^2 + \sigma_{\text{instrumental}}^2} = 0.8\mu as.h^{-1/2} \]

\[ T_{\text{visit}} = \frac{\text{SNR}^2 \left( \sigma_{\text{target}}^2 + \sigma_{\text{instrumental}}^2 + \frac{F_{\text{base}}}{F_{\text{ref}}} \sigma_{\text{ref.0}}^2 \right)}{A^2 N_{\text{indep.data}}} \]

If the dominant noise is photons of reference stars: 

\[ T_{\text{visit}} = \frac{\text{SNR}^2 \sigma_{\text{ref.0}}^2}{A^2 N_{\text{indep.data}}} \times \frac{F_{\text{base}}}{F_{\text{ref}}} \]
Choice of an observational strategy (NEAT)

Sample of target stars unbiased for F, G and K stars. Sample of detected planets biased because of detection threshold dependence on:

- Astrometric signal (spectral type, distance)
- Target magnitude
- Reference stars number and magnitude
- Instrumental noise

- Allocation of different observation times for each star: more time can be spent on easy targets
- The choice of an observational strategy will affect the statistics of the target stars
Choice of an observational strategy (NEAT)

• Strategy 1: observation of all targets with equal time.

• Strategy 2: the time per target is set to yield a chosen mass threshold in HZ, the threshold is changed when the integration time is “too long”.

• Strategy 3: the time per target is a function of the stars parameters (mainly astrometric signal in HZ and flux of reference stars). More time is spent on easier targets.
The reference stars

Crossmatch with the Tycho catalog: selection of the stars with Vmag < 11 within 0.3 deg of the target stars (NEAT FoV)

More realistic selection of reference stars has to include:
- a minimal distance
- the spectral type (good reference stars are mostly K giants, not M’s)
- condition about multiplicity? (do we have to exclude binaries?)
Availability of the reference stars

Crossmatch with the Tycho catalog: selection of the stars with Vmag < 11 within 0.3 deg of the target stars

Remark: 9 stars without reference stars (not present on the histogram)

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Equivalent flux of the reference stars

The NEAT error budget assumes 6 stars of
Magnitude < 11 for each target star

Eq. Mag. = “\( \sum \) magnitude of reference stars”

6 stars of mag 11 => Mag eq. = 9

Most stars have a Eq. Mag. Smaller than 9.

Would this still be true with a more restrictive selection of reference stars?
Conclusion

• The catalog of NEAT targets and reference stars can provide the distributions for a final sample of target and reference stars: distance, spectral type, target magnitude, astrometric signal, number and magnitude of references per target.

• Good availability of reference stars, but need to refine the selection to have a more realistic sample. This is critical to put realistic noise/number of reference stars.

• Determination of a theoretical detection threshold: possibility of comparison with the double blind test result.
  ➢ The dependence of this threshold on the properties of the target and references is important to define the observational strategy.

• Can resolved binary targets be used as references?
Conclusion

- NEAT catalog of targets and references
- Parameter distributions of the targets and references
- Observational strategy
- Validation of the observational strategy
- Theoretical and Tvisit/mass threshold relation
- NEAT error budget
- Validation of the Tvisit/mass threshold relation
- NEAT double blind test